SECTION 5.2: GROUNDWATER

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GLOSSARY

Aquifer: Rock or sediment in a formation, group of formations, or part of a formation which is saturated and sufficiently permeable to transmit economic quantities of water to wells and springs.

Baseflow: That part of stream discharge from ground water seeping into the stream.

Consumptive use: That portion of the water use that is not returned to the aquifer of stream.

Eocene: Second epoch of the Tertiary period; Paleocene below and Oligocene above; also the series of strata deposited during that epoch.

Equipotential surface: A surface in a three-dimensional ground-water flow field such that the total hydraulic head is the same everywhere on the surface.

Evaportranspiration: The evapotranspiration that actually occurs under given climatic and soil moisture conditions.

Gaining streams: A stream or reach of a stream where surface flow is increasing due to inflow of ground water. Also known as an effluent stream.

Ground water: The water contained in interconnected pores located below the water table in an unconfined aquifer or located in a confined aquifer.

Holocene: Recent; that period of time (an epoch) since the last ice age (Wisconsin in North America); also the series of strata deposited during that epoch.

Hydraulic conductivity: A coefficient of proportionality describing the rate at which water can move through a permeable medium. The density and kinematic viscosity of the water must be considered in determining hydraulic conductivity.

Hydraulic gradient: The change in total head with a change in distance in a given direction. The direction is that which yields a maximum rate of decrease in head.

Hydraulic head: The sum of the elevation head, the pressure head, and the velocity head at a given point in an aquifer.

Geohydrologic unit: A formation, part of a formation, or group of formations in which there are similar hydrologic characteristics allowing for grouping into aquifers or confining layers.

Losing stream: A stream or reach of a stream that is losing water by seepage into the ground. Also known as an influent stream.

Milocene: The fourth of the five epochs into which the Tertiary Period is divided. Also the series of strata deposited during that epoch.

Quaternary: The younger of the two geologic periods or systems in the Cenozoic Era (providing Neogene and Paleogene are not used, *q.v.*). Quarternary is subdivided into Pleistocene and Holocene (or Recent) epochs or series. It comprises all geologic time or rocks from the end of the Tertiary to and including the Holocene (or Recent).

Recharge area: An area in which there are downward components of hydraulic head in the aquifer. Infiltration moves downward into the deeper parts of an aquifer in a recharge area.

Return flow: That portion of water use that is returned to the aquifer or stream.

Specific capacity: An expression of the productivity of a well, obtained by dividing the rate of discharge of water from the well by the drawdown of the water level in the well. Specific capacity should be described on the basis of the number of hours of pumping prior to the time the drawdown measurement is made. It will generally decrease with time as the drawdown increases.

Specific yield: The ratio of the volume of water a rock or soil will yield by gravity drainage to the volume of the rock or soil. Gravity drainage may take many months to occur.

Transmissivity: The rate at which water of a prevailing density and viscosity is transmitted through a unit width of an aquifer or confining bed under a unit hydraulic gradient. It is a function of properties of the liquid, the porous media, and the thickness of the porous media.

Water balance budget: An evaluation of all the sources of supply and the corresponding discharges with respect to an aquifer or a drainage basin.

SECTION 5.2: GROUNDWATER

INTRODUCTION

This section summarizes available information regarding hydrogeologic setting and groundwater resources in Water Resources Inventory Area (WRIA) 11, Lower Nisqually Basin.

METHODS

Generalized studies on the geology/hydrogeology and groundwater conditions of the study area were compiled from the U.S. Geological Survey (USGS), Washington State Department of Ecology (Ecology), Washington State Department of Natural Resources (DNR), and other agencies. Information regarding production well installation and well locations within the study area was obtained from the major water purveyors and the Ecology water well database. Aquifer yield was determined from regional reports and individual production well installation reports, as provided. Groundwater levels for aquifers in the northern portion of the study area (McAllister, Yelm and Muck/Murray subbasins) were compiled from data presented in various USGS and private consulting reports, and water purveyor information (Griffin and others, 1962). Groundwater levels for aquifers in the basin were also compiled from information obtained from the cities of Lacey, Olympia and Yelm, Town of Eatonville, Nisqually Indian Tribe, Graham Hill Mutual Water Company, McKenna Water District, and Pierce/Thurston Counties. The results of two regional groundwater studies for aquifers located in the study area were also reviewed (Drost, B.W., D.M. Ely, and W.E. Lum, II, 1999; AGI/CDM Technologies, 1999). A complete listing of information reviewed for this Level I Technical Assessment is provided in the reference list accompanying this report.

GEOLOGIC SETTING

GENERAL

The geology of WRIA 11 is highly varied and complex. Detailed descriptions of the geologic and/or hydrogeologic setting of portions of WRIA 11 have been provided by Bretz (1910, 1911, 1913), Mundorff et al (1955), Snavely and others (1958), Crandell and others (1958 and 1965), Nobel and Wallace (1966), Thorson (1980), Easterbrook and

others (1981), Lea (1984), Gower and others (1985), Walsh (1987), Dion and others (1994), Jones and others (1999), Drost and others (1999), and AGI/CDM Technologies (1999). We have also reviewed geologic information made available in numerous consulting reports for the Cities of Olympia, Lacey and Yelm, Nisqually Tribe, and water system plans for Graham Hill Mutual Water Company and the Town of Eatonville. Additional/supplemental information regarding basin geology can be found in Chapter 2. We understand that several of the publications cited in this chapter regarding the geologic/hydrogeologic setting of portions of WRIA 11 have received critical review comments and that they are in the process of being revised. It should be noted that some of the information and conclusions presented in this chapter may be affected by the results of future revisions to these supporting documents.

The geologic/hydrogeologic conceptual model presented in this report is primarily based on the conceptual and numerical models developed by the USGS (Drost and others 1999) for unconsolidated sediments in Thurston County. The USGS conceptual model is based on limited subsurface information and generally defaults to an interpretation of relatively uniform/homogenous subsurface conditions. Consequently, the USGS numerical model provides a very general, macro-scale, evaluation of groundwater flow, recharge, and discharge patterns in the lower portion of WRIA 11. It is highly likely that the geologic/hydrogeologic conditions present in WRIA 11 are significantly more complex than assumed in the USGS models. Furthermore, there are significant limitations in applying the USGS model for specific interpretations of groundwater flow, discharge, and recharge at the subbasin level. For instance, the model was able to account for only 17 percent of the total recharge in the study area.

AGI/CDM has also developed a conceptual model for the McAllister Creek subbasin. The details of the AGI/CDM's conceptual model fare presented in their Technical Memorandum #3 to the Public Works Departments of the Cities of Olympia and Lacey dated December 13, 1999. The AGI/CDM conceptual model is specific to the McAllister subbasin and presents a significantly more complex hydrogeologic/geologic setting than the USGS model. A brief comparison of the two conceptual models is presented on Table 5.2-2.

Currently, AGI/CDM Technologies (AGI/CDM) is in the process of developing a numerical groundwater flow model of a large area extending from Olympia to the Nisqually, including the McAllister Creek subbasin. The new model should be available for public review/comment in early 2002. It is likely that the AGI/CDM numerical model will provide significantly more detail on groundwater flow, water use, recharge, and discharge in this subbasin.

GEOLOGY

The following is a description of the characteristics of the unconsolidated glacial and non-glacial deposits and bedrock that are present in WRIA 11. A summary of these characteristics is presented on Table 5.2-1.

◆ Holocene age alluvial and deltaic sand and gravel (Qa) is the youngest geologic unit in the study area. This unit is generally found along the valley bottoms of Nisqually River and principal streams and is of limited extent.

◆ The next youngest unit is Vashon-age recessional outwash (Qvr and Qvrm) deposited by streams flowing off the melting/retreating glacier. This unit mantles a great deal of the western portion of WRIA 11 and generally consists of well-sorted sand and gravel. This unit also includes glacial drift (terminal moraine) that was deposited at the terminus of the stationary or slowly retreating ice mass near Lake St. Clair (Noble and Wallace, 1966). Numerous small to moderate size kettle lakes have formed in this terrain, including Lake St. Clair.

◆ The recessional outwash is generally underlain by Vashon glacial till (Qvt), which is commonly referred to as "hard pan" or "boulder clay" on well drillers logs. The till generally consists of compacted, unsorted deposits of clay, silt, sand and gravel with some boulders that was deposited beneath the glacial ice as it advanced over the study area.

◆ The till unit is generally underlain by Vashon advance outwash (Qva) that was deposited by meltwater streams in front of the advancing glacier. The Vashon advance outwash is generally comprised of fine- to coarse-grained stratified sand grading upward to a sandy gravel with some lenses of silt and clay. Vashon advance outwash is generally found at depth over most of the western portion of WRIA 11.

◆ The Vashon advance outwash is underlain by a non-glacial unit that is generally comprised of silt and clay with minor amounts of sand, gravel, peat, and wood. This unit is most likely the Kitsap Formation (Qf) and is thought to have been deposited in shallow lakes and swamps (Drost and others, 1999).

◆ Below the Kitsap Formation is a pre-Vashon glacial unit (Qc) that was originally referred to the Salmon Springs Drift(?) by Noble and Wallace (1966). The unit

consists of a coarse stratified sand and gravel that is commonly stained with iron oxides to a yellowish brown or reddish brown color (Dion and others, 1994).

⬥ The Salmon Springs Drift(?) is underlain by a sequence of unconsolidated fine- to coarse-grained sediments (TQu) that extends to bedrock. It is likely that these sediments are probably both glacial and nonglacial in origin.

⬥ More than 60 percent of the Upper Basin and Mashel subbasins, and 35 percent of the Toboton/Powell/Lackamas and Tanwax/Kreger/Ohop subbasins were not covered by continental glacial ice and the surficial geology in these areas generally consists of Miocene to Eocene sedimentary and volcanic bedrock (Tb). The top of the bedrock surface generally slopes downward to the northwest from ground surface near Eatonville to over 2,000 feet below mean sea level in the northwest portion of WRIA 11 (Drost and others, 1999).

Table 5.2-1. Hydrologic characteristics of geohydrological units.

System	Series	Geologic Unit		Geo-hydrologic Unit[1]	Typical Thickness (feet)	Lithologic Characteristics	Hydrologic Characteristics	Hydraulic Conductivity (ft/d)	Transmissivity (ft2/d)
Quaternary	Holocene	Alluvium		Ovr Ovm	10-40	Alluvial and deltaic sand and gravel along major water courses. Moderately to well-sorted glacial sand and gravel, including kettled end moraine	An aquifer where saturated groundwater is mostly unconfined. Perched conditions occur locally	10-2,000	
		Vashon Drift	Recessional outwash and end moraine						
	Pleistocene		Till	Ovf	20-55	Unsorted sand, gravel, and boulders in a matrix of silt and clay.	Confining bed, but can yield usable amounts of water. Some thin lenses of clean sand and gravel.	5-100	
			Advance outwash	Ova	10-45	Poorly to moderately well-sorted, well-rounded gravel in a matrix of sand with some sand lenses	Groundwater, mostly confined. Used extensively for public supplies near Tumwater	10-130,000	
		Kitsap Formation		Of	20-70	Predominantly clay and silt, with some layers of sand and gravel. Minor amounts of peat and wood.	Confining bed, but in places yields usable amounts of water.	0.05-60	
		Salmon Springs (?) Drift (Noble and Wallace 1966) / Deposits of "penultimate" glaciation (Lea 1984)		Oc	15-70	Coarse sand and gravel, deeply stained with red or brown iron oxides	Water is confined. Used extensively for industrial purposes near Tumwater.	2-12,000	24,000-430,000
		Unconsolidated and undifferentiated		Tqu	Not known	Various layers of clay, silt, sand and gravel of both glacial and nonglacial origin.	Contains both aquifers and confining beds. Water probably confined.	1-4,000	
Tertiary	Miocene and Eocene	Bedrock		Tb	Not known	Sedimentary rocks consisting of claystone, siltstone, sandstone, and minor beds of coal. Igneous bodies of andesite and basalt	Poorly permeable base of unconsolidated sediments. Locally an aquifer, but generally unreliable. Water contained in fractures and joints. Well yields relatively small. Numerous abandoned wells.	0.003-450	

Notes:

¹ Geohydrologic units as presented in Drost and others

² Includes "late Vashon lake deposits" (Washington State Department of Ecology, 1980). May include till of "penultimate" glaciation (Lea 1984)

³ Includes alluvium younger than Kitsap Formation in Nisqually River delta. May include some Vashon till (where multiple tills are present). May include till of "penultimate" glaciation (Lea 1984).

Table 5.2-2. Comparison of USGS and AGI/CDM Conceptual Models. (See text for discussion of new AGI/CDM new model.)

	Feature	USGS Model	AGI Conceptual Model
System Description	Aquifers/Aquitards	A series of horizontal, layered sediment bodies defined by origin and age; assumed to have uniform permeability; layers occur in an alternating sequence of aquifers and aquitards	Interbedded high and low permeability sediments; local aquitards with high permeability sediments hydraulically connected in three dimensions
	McAllister Gravel	A high permeability aquifer including McAllister Springs and wellfield; extends from south of Lake St. Clair to Nisqually Delta	A higher permeability portion of the McAllister Aquifer occurring between Lake St. Clair and McAllister Springs
	Permeability	Aquifer transmissivity described for pumping and monitoring wells	Hydraulic conductivities assigned to textural units; categorized into high and low permeability units shown on maps for 50-foot thick layers
	Water Levels	Generalized by shallow and deep aquifers	Contoured for permeability differences; shown for selected 50 foot thick layers
	McAllister Springs	Discharge site for 25% of the groundwater in the McAllister gravel	The discharge site for 64% of the groundwater; clay in the lower McAllister valley controls its location
	Lake St. Clair	Water table lake in the Sea Level Aquifer	A partially perched lake in the Sea Level Aquifer
Predicted Impacts	McAllister Wellfield Source of Water	Assumes the wellfield will withdraw equally from the Nisqually River, McAllister Creek, and McAllister Springs.	Water budget and predicted drawdown indicates at least 64% and perhaps as much as 100% of the water from McAllister and Abbott Springs
	Lake St. Clair	Induced seepage between 96 and 415 gpm; water level lowering of 9.6 inches	Induced seepage between 13 and 27 gpm; water level lowering between 0.7 and 2.0 inches
	McAllister Creek	Increased flow equal to 66% of wellfield withdrawals	Increased flow equal to 36% of wellfield withdrawals
	Kettle Lakes	Water level lowering between 1.5 and 3.5 feet; some significant impacts	Water level lowering between 1.6 and 2.0 feet; no significant impacts
	Nisqually River	Predicted one-foot water table lowering beneath river on Nisqually reservation; additional 6 cfs baseflow reduction to lower river.	No water table lowering on Reservation because of Nisqually Groundwater Divide; 10.9 cfs baseflow reduction below RM 4.1

Reference: AGI Technologies, 1999

HYDROGEOLOGIC SETTING

GENERAL

The regional hydrogeologic setting and groundwater characteristics of McAllister and Yelm subbasins (Dion and others, 1994; Drost and others, 1999; AGI/CDM Technologies, 1999), western half of the Toboton/Powell/Lackamas subbasin (Drost and others, 1999), and the north half of Muck/Murray subbasin (Griffin and others, 1962) have been described in detail in numerous publications. The geology/hydrogeology of the Upper Nisqually Basin has been summarized by David Evans and Associates (2000). Detailed comprehensive, regional hydrogeologic studies have not been completed in the Tanwax/Kreger/Ohop, Mashel and Toboton/Powell/Lackamas subbasins to date. Therefore, the understanding of the regional hydrogeology of these areas is limited to information available on water well reports for wells completed in these subbasins, various consulting reports for production well installations, and water system plans for various communities. It is likely the general geohydrologic stratigraphy presented by Drost and others (1999) is reasonably valid at a screening level for areas of the WRIA that are underlain by a substantial thickness unconsolidated glacial and non-glacial sediments such as the Muck/Murray, Yelm and portions of the Tanwax/Kreger/Ohop and Toboton/Powell/Lackamas subbasins. However, large portions of the Toboton/Powel/Lackamas, Tanwax/Kreger/Ohop and Mashel subbasins are underlain by bedrock and many of the geohydrologic units described by Drost (1999) might not be present in these areas.

Information regarding the number and approximate location of wells within the study area was provided by Ecology. There are approximately 2,865 well records in the Ecology database, distributed in the subbasins as follows: McAllister 200, Muck/Murray 1,480, Yelm 510, Toboton/Powell/Lackamas 110, Tanwax/Kreger/Ohop 425 and Mashel 140 subbasins. The database indicates another approximately 200 wells are located in the Upper Nisqually subbasin. It should be noted that the number of wells included in the Ecology database likely only reflects a fraction of the actual wells completed in the study area. Furthermore, the locations of these wells are approximate and based on information presented on well logs that are often in error. However, the database is helpful in that is gives an idea of the relative density of wells in each of the subbasins. The approximately distribution of these wells is shown on Figure 5.2-1.

GEOHYDROLOGIC UNITS

Drost and others (1989) differentiated the previously described geologic units into seven major geohydrologic units. These geohydrologic units are summarized in Table 5.2-1 and described below. More detailed descriptions of these geohydrologic units are presented in Dion and others (1994), Drost and others (1999), and AGI/CDM Technologies (1999). A broad conceptual model of the groundwater flow system beneath WRIA 11, after Drost (1999), is presented on Figure 5.2-2.

Holocene alluvium (Qa) and Vashon recessional outwash (Qvr/Qvrm) are combined as a single geohydrologic unit because of their lithologic similarities for the purposes of this report. It should be noted that this may not be valid for the lower Nisqually delta area where the alluvium (deltaic sediments) is very fine grained and can act as a confining unit (AGI/CDM, 1999). This unit can be a productive aquifer and is used locally as a water supply source. Numerous domestic wells are completed in the Qvr and they produce moderate amounts of water. Furthermore, the Holocene alluvium can be a significant source of water in the Tanwax/Kreger/Ohop, Toboton/Powell/Lackamas and Mashel subbasins. Groundwater occurs in this unit generally under water table (unconfined) conditions. This unit is generally 10 to 40 feet thick, where present, but locally can be much thicker. Perched groundwater conditions can occur in areas where the Qvr is underlain by the relatively low permeability till.
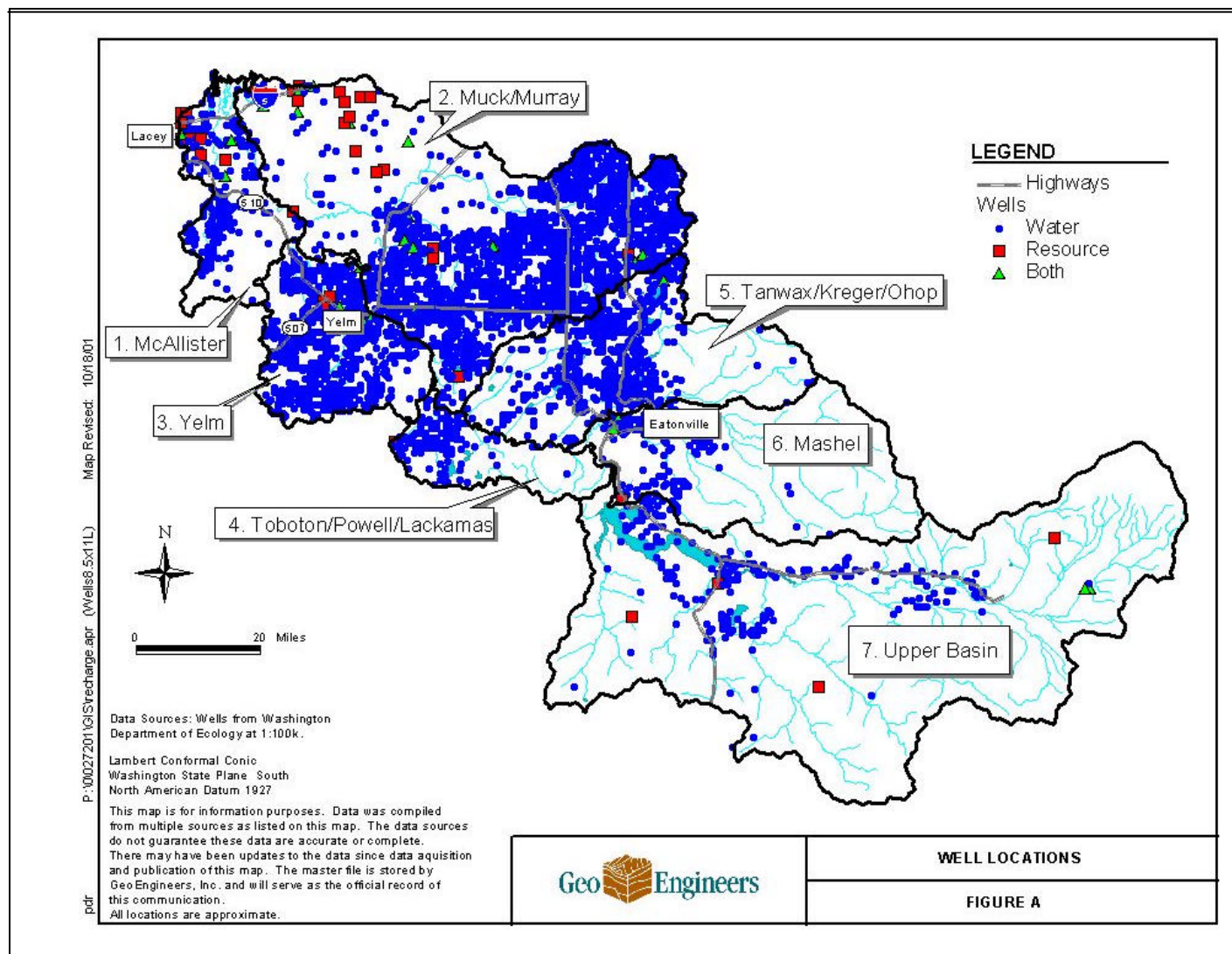
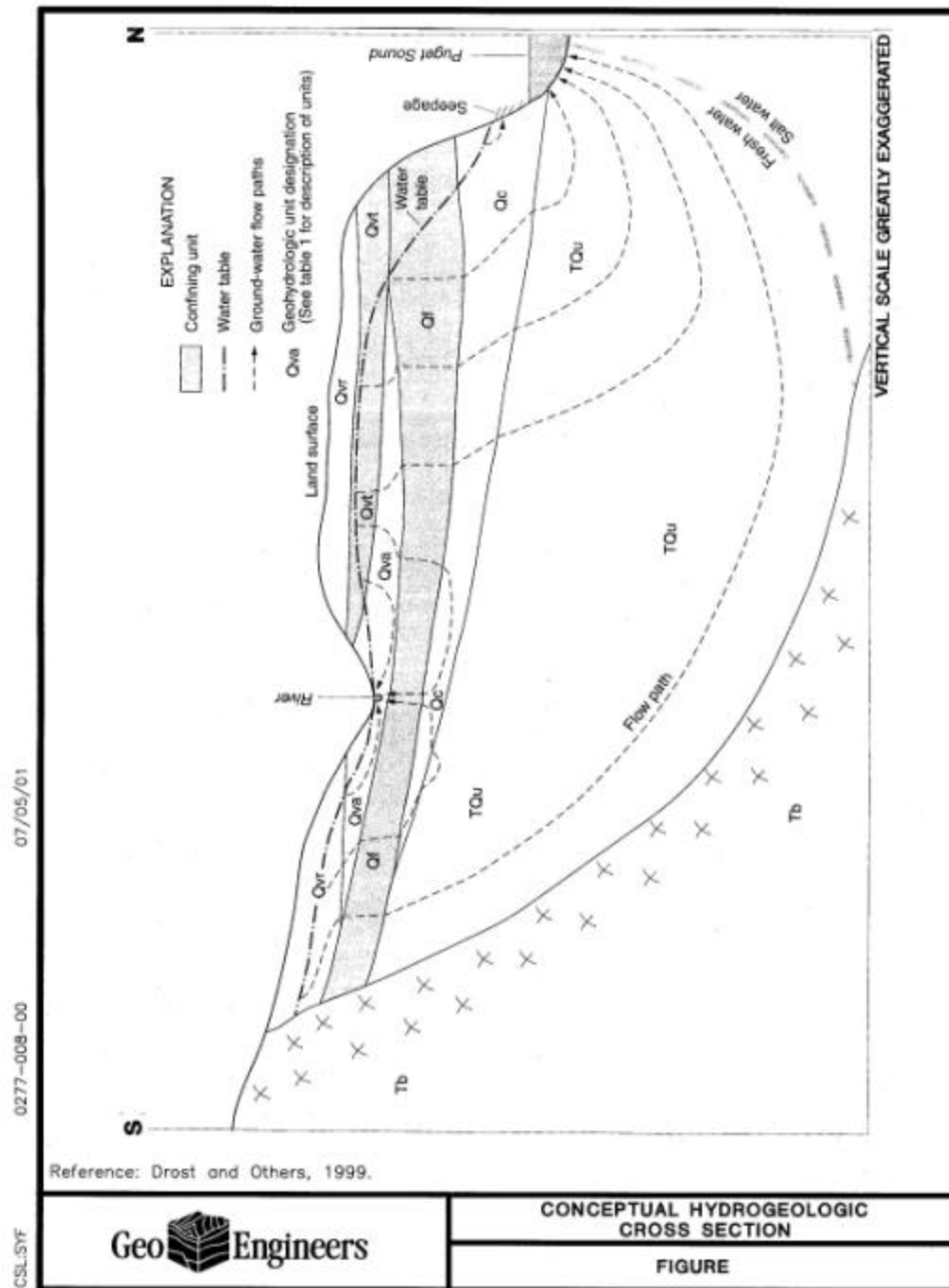**Figure 5.2-1. The approximate distribution of wells in the basin.**

Figure 5.2-2. Conceptual hydrogeologic cross section

The Vashon till (Qvt) makes up the next geohydrologic unit. This unit is a poor source of water and generally acts as a confining layer. This unit is common at or near the ground surface in the northwest portion of WRIA 11 and generally ranges in thickness between 20 and 55 feet, where present. Some shallow domestic wells have been completed within the Qvt. These wells usually have a low yield and tend to go dry in late summer.

Vashon advance outwash (Qva) is an important aquifer in the study area. Many domestic wells are completed in the Qva aquifer in WRIA 11. The Qva geohydrologic unit is generally between 10 and 45 feet thick but can exceed 100 feet in local areas. The Qva aquifer is generally confined and is located between elevations of 50 to 400 feet above mean sea level. Wells completed within the Qva usually have a moderate to high yield.

The Kitsap Formation and other low permeability units occurring beneath the Qva are included in geohydrologic unit Qf. This unit generally acts as a confining bed but local more permeable lenses are utilized for water supply purposes. Where present, the Qf unit is generally between 20 and 70 feet thick, but locally is greater than 150 feet thick.

The water-bearing Salmon Springs(?) Drift, penultimate deposits, and other coarse-grained deposits are grouped into one geohydrologic unit Qc. This unit is present beneath most of the McAllister, Muck/Murray and Yelm subbasin, and likely beneath portions of the Toboton/Powell/Lackamas and Tanwax/Kreger/Ohop subbasins and possibly the Mashel subbasin. The Qc unit is extensively utilized as a source of groundwater where it is present in the study area. Numerous highly productive wells are completed in this high permeability unit. Groundwater is primarily under confined conditions and the unit averages in thickness between roughly 15 to 70 feet thick. The top of the Qc unit is generally between 50 and 400 feet above mean sea level where present within the study area.

Unconsolidated glacial and non-glacial sediments located beneath the Qc unit were designated as geohydrologic unit TQu. Drost and others (1999) report that several hundred wells tap various permeable water-bearing units within the TQu in Thurston County; however, the unit is not extensively developed in the study area. Groundwater occurs under confined conditions in the TQu unit. The entire thickness of the TQu unit is unknown but it may be several thousand feet thick in the northwestern portion of WRIA 11.

The entire WRIA is underlain at depth by Tertiary age bedrock designated as geohydrologic unit Tb. Small quantities of groundwater can be obtained from fractures and joints that are more numerous near the top of the unit. Groundwater yield from this unit is generally low and water quality is usually poor. However, this unit can be an important source of domestic water in local areas. Particularly, in local areas of Toboton/Powell/Lackamas, Tanwax/Kreger/Ohop and Mashel subbasins where the more permeable water-bearing, unconsolidated sediments are not present.

As previously discussed, WRIA 11 is generally underlain by a substantial thickness of glaciofluvial sediments that contain several aquifers. It should be noted that many of these glaciofluvial sediments and aquifers also extend beneath portions of WRIAs 12 and 13, located north and south of WRIA 11, respectively. Therefore, it is highly likely that some natural groundwater exchange occurs not only between subbasins in WRIA 11 but also with other adjacent WRIAs along their common surface water boundaries. Furthermore, this exchange of groundwater between subbasins and adjacent WRIAs can be increased due to significant pumping of aquifers. A detailed evaluation of the precise areas and volumes of significant groundwater exchange between the subbasins and surrounding WRIAs is beyond the scope of this Level I assessment.

GROUNDWATER RECHARGE

General

Recharge to the groundwater system in the study area is primarily through the infiltration of precipitation and secondarily as seepage from surface water (lakes, ponds and streams), and from anthropogenic affects (septic system, irrigation return flow, water reuse, etc). Precipitation induced recharge generally occurs throughout the study area with the exceptions of areas of groundwater discharge (areas near major streams and low-lying coastal areas) and areas covered by impervious surfaces. Groundwater recharge also occurs in local areas of the WRIA from the infiltration of storm water runoff (the other text is redundant to earlier in the paragraph)

Precipitation Induced Recharge

The average annual amount of precipitation induced recharge to the groundwater system in WRIA 11 was estimated using the precipitation-recharge relationships developed for surface geologic units as presented in Dion and others (1994) and Drost and others (1999), and by the climatic water budget method as described later in this

chapter. Precipitation-recharge relationships were developed by the USGS for primary geologic units that are exposed at the ground surface in WRIA 11 (bedrock, till, outwash and kettle outwash). The precipitation-recharge relationship for bedrock was arbitrarily assumed as half that for till in the study area (Dion and others, 1999). The recharge characteristics of Qf and TQu were assumed to be the same as Qvt because of similar hydrologic properties (Dion and others, 1994). The precipitation-recharge relationships for the primary surface geologic units (bedrock, till, outwash and kettle outwash), as presented by Dion and others (1994), are shown on Figure 5.2-3. A summary of the annual recharge estimates for the subbasins is presented in Table 5.2-3. The spatial distribution of annual recharge, estimated using the precipitation-recharge relationship described above, is shown on Figure 5.2-4.
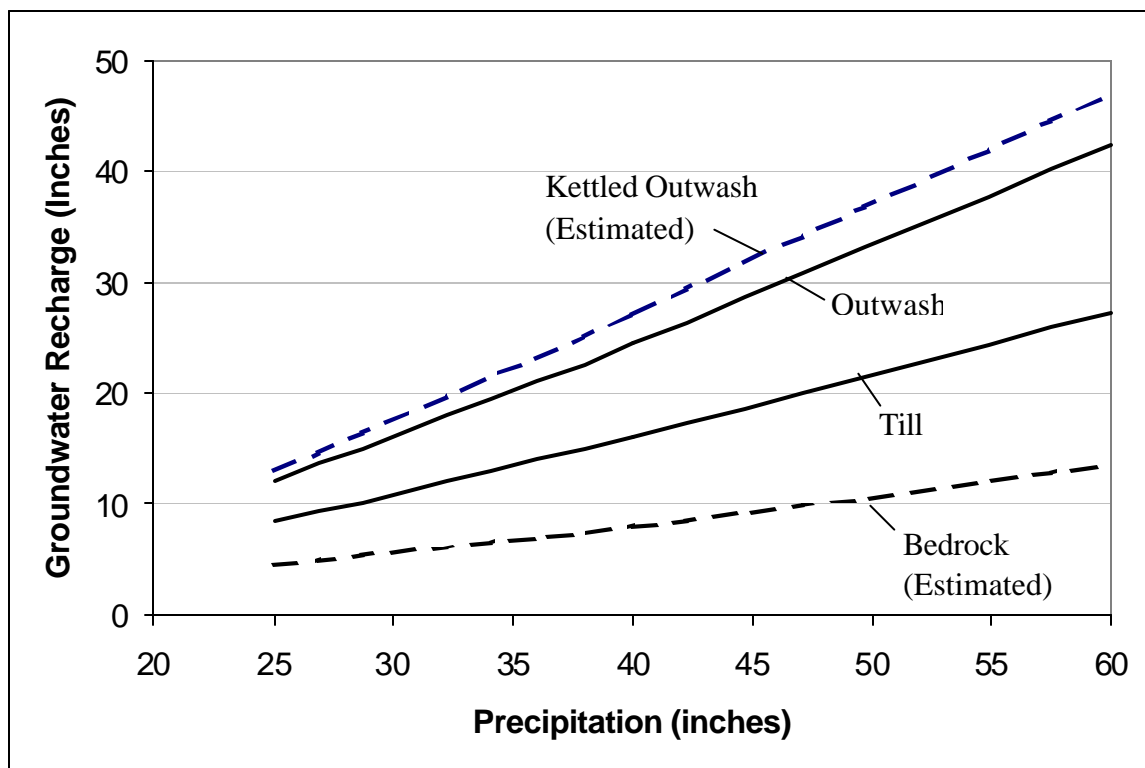
Figure 5.2-3. Precipitation-recharge relationship.

LEGEND

Highways
Sub Basin Boundarys
Anual Recharge (inchs/year)
0 - 20
20 - 40
40 - 60
60 - 80
80+
Open Water, Ice

N

0   20   Miles

Map Revised: 10/18/01

P:\00027201\GIS\recharge.apr   (Wells8.5x11L)

pdr

Lambert Conformal Conic
Washington State Plane South
North American Datum 1927

This map is for information purposes. Data was compiled
from multiple sources as listed on this map. The data sources
do not guarantee these data are accurate or complete.
There may have been updates to the data since data aquisition
and publication of this map. The master file is stored by
Geo Engineers, Inc. and will serve as the official record of
this communication.
All locations are approximate.

Geo Engineers

RECHARGE MAP

FIGURE D

Figure 5.2-4. Recharge Map

To estimate the distribution of mean annual recharge in each of the subbasins, the average long-term annual precipitation map (Figure 2-7) was overlaid on the geologic map of the study area and the previously discussed precipitation-recharge relationships for the primary geologic units (bedrock, till, outwash and kettle outwash) were applied. The result was a map showing the general distribution of annual recharge from direct precipitation in each of the subbasins (Figure 5.2-4). Annual recharge estimates were also derived from monthly values of groundwater recharge estimated using the climatic water balance methodology as described later in this chapter. The values of annual recharge estimated using the USGS precipitation-recharge relationship and the climatic water balance methodology compare well for the McAllister, Muck, Yelm, and Toboton/Powell/Lackamas subbasins (Table 5.2-3). However, the annual recharge values estimated for the Tanwax/Kreger/Ohop and Mashel subbasins using the climatic water balance methodology are significantly greater than the values estimated using the USGS methodology (Table 5.2-3).

Table 5.2-3. Summary of annual groundwater recharge. All values are in inches.

Subbasin	Climatic Water Balance	USGS Precipitation Recharge
McAllister	29.3	26.6
Muck/Murray	23.7	21.5
Yelm	24.9	22.3
Toboton/Powell/Lackamas	16.4	15.2
Tanwax/Kreger/Ohop	23.3	16.6
Mashel	36.9	22.5

To check the results of the USGS precipitation-recharge relationships, Dion and others (1994) completed a detailed rainfall-runoff model of a portion of Thurston County, which included the entire McAllister subbasin and a portion of the Yelm subbasin. The rainfall-runoff model (U.S. EPA, 1984) was run using climatologic data for 28 consecutive years (1961 through 1988) and included independent variables for precipitation, air temperature, evapotranspiration, soil type, land cover, land slope, and available water capacity of the soil. The results of the rainfall-runoff model indicated an average groundwater recharge value of approximately 22 inches/year compared to an average recharge value of 28 inches/year estimated by the USGS precipitation-recharge relationship for the same area. Based on these results, Dion and others (1999) concluded that an average mean recharge value of approximately 25 inches/year was reasonable for northern Thurston County. This value of 25 inches/year for precipitation recharge was

further supported during the calibration of a groundwater model for approximately the same study area (Drost and others, 1999). Current estimates of the quantities of groundwater available in the McAllister subbasin appears contradict the assessment of recharge area and precipitation-recharge relationships. Further study on these relationships is warranted in order to accurately assess contributions by through-flow from outside the subbasin.

The average annual groundwater recharge (25 inches/year) assumed by the USGS for their groundwater flow model compares well to the range of annual groundwater recharge estimated by the climatic water balance method and the USGS precipitation-recharge method for the McAllister, Muck/Murray and Yelm subbasins (Table 5.2-3). Therefore, for the purposes of this Level I Assessment, it was assumed that the average annual groundwater recharge in each of the subbasins was within the range of values estimated by the water balance and precipitation-recharge relationship (Table 5.2-3). These numbers were used for the purposes of this Level I assessment. Work currently underway by AGI/CDM may provide additional information.

In the southeastern portion of WRIA 11 (primarily Mashel and Tanwax/Kreger/Ohop subbasins), a large percentage of the ground surface above approximate Elevation 1,000 feet is composed of low-permeability bedrock. It is possible that the water balance derived relationship may not accurately estimate groundwater recharge in these areas because of the lack of adequate information on surface water runoff.

Recharge from Surface Water

Groundwater likely discharges to surface water in WRIA 11 during most of a typical year. However, it is possible that certain reaches of some streams recharge the shallow groundwater system during late summer and early fall months. Streams that recharge groundwater are usually termed losing streams. Streams that receive seepage from groundwater are termed gaining streams. Data presented by the USGS suggests that Lake St. Clair provides a significant amount of recharge to groundwater in the McAllister subbasin (Drost and others, 1999). Water balance calculations for the Lake St. Clair area indicate a net flow to the groundwater system of approximately 4,000 acre-feet per year (ac-ft/y) in this area during the 1988-1989 water year. It should be noted that the USGS model could account for only 54,000 acre-ft per year of recharge out of a total estimated recharge of 310,000 acre-ft per year. They attribute the difference to charging of deeper aquifers, lakes, seeps, and springs. We understand that Ecology is currently studying

groundwater/surface water hydraulic continuity in the Muck/Murray Creek subbasin. The results of this Ecology study may add additional information regarding potential recharge from surface water to groundwater. The Ecology report should be available for public review in late fall of 2001 (is it really fall of 2001??) (Sinclair, 2001). No additional information was available that quantified recharge from surface water to groundwater in the WRIA.

Anthropogenic Recharge

Human induced recharge occurs in many locations of the WRIA from septic system, irrigation, leakage from water/sewer lines, and direct infiltration of surface water runoff (infiltration ponds, dry wells, etc.). We were unable to locate sufficient information regarding groundwater recharge due to leaking water/sewer lines and the infiltration of storm water runoff to estimate potential groundwater recharge from these sources. However, we anticipate that the potential volume of groundwater recharge in WRIA 11 due to these sources is small.

The City of Yelm currently operates a wastewater reclamation project that returns treated wastewater to surface water and groundwater systems in the immediate vicinity of the City. The Class A reclaimed water is used as direct augmentation of surface water flow, as summer irrigation and as groundwater recharge. The reclamation project provides approximately 56 acre-feet of increased groundwater recharge annually to the shallow aquifer system in the immediate vicinity of the City. In Addition, roughly 168 acre-feet per year of Class A reclaimed water is used to augment surface water flows and for summer irrigation.

Groundwater recharge due to the infiltration of effluent beneath septic drainfields (return flow) was assumed to be 87 percent (Solly and others, 1993) of the single-family domestic water use in areas of the subbasin that are not serviced by a regional sewer system. Return flow in areas serviced by sewer systems (City of Lacey/McAllister subbasin and Town of Eatonville/Mashel subbasin) was assumed zero for in-house use and 57 percent of outdoor use. Groundwater recharge due to irrigation return flow was assumed 57 percent of total irrigation use in each subbasin of this report. A summary of the estimated amounts of return flow for each subbasin is summarized in Tables 5.4-6, 5.4-7, and 5.4-9 of Chapter 5, Section 5.3.

Groundwater Discharge

Groundwater in WRIA 11 discharges as seepage to lakes, streams, wetlands, and springs; as evapotranspiration of shallow groundwater; as submarine flows to Puget Sound; and due to pumping of wells. A summary of groundwater and surface water use in the subbasins is presented in Section 5.3 of this report.

Groundwater discharge in late summer and early fall generally sustains flows in the Nisqually River and other streams located in the study area. The USGS conducted a seepage study on the Nisqually River at McKenna and at the Interstate 5 crossing in October 1991. The results of this seepage study indicated that the Nisqually River was receiving recharge from the shallow groundwater system (Drost, 1999). In other words, the Nisqually River was a gaining stream in these areas during the time the study was conducted. Pacific Groundwater Group (PGG) completed a seepage inflow study of McAllister Creek for the City of Lacey (PGG, 2000). PGG concluded that groundwater inflow to McAllister Creek is from three principal sub-surface sources including inflow from surrounding floodplain sediments, inflow from the upland aquifer systems (Qvr and Qva), and inflow from the sea-level aquifer system (Qc).

Groundwater Flow Direction and Elevation

Primary aquifers in the study area include the Qvr, Qva, Qc, and TQu geohydrologic units. Fracture zones within the Tb unit may also be locally important aquifers in the Toboton/Powell/Lackamas, Tanwax/Kreger/Ohop and Mashel subbasins. Regional information regarding groundwater flow direction and elevation in these aquifers is available for portions of the McAllister and Yelm subbasins (PGG, 1993; Dion and others, 1994; Drost and others, 1999; AGI/CDM, 1999) and the Muck/Murray subbasin (Griffin and others, 1962; Walters and Kimmel, 1968). Additional information regarding groundwater flow direction and/or elevation in local areas of the study area is presented in numerous water system and consulting reports (Robinson & Noble, 1996 and 2000; Kleinfelder, 2001). The regional information regarding groundwater elevations and the general direction of groundwater flow primarily in the Qva and Qc aquifers within the study area is displayed on Figure 5.2-5. The following is a summary of information regarding groundwater flow direction and elevations in the study area.

- Groundwater flow direction in the Qvr aquifer generally follows the ground surface topography in portions of the study area where the Qvr aquifer is underlain by relatively impermeable Qvt.

- The City of Yelm has four production wells (Well 1, 2, 3 and 3A) located in Sections 19 and 20, Township 17 North, Range 2 East. We understand that production well 3 is currently not used. The wells are reported to be within a shallow unconfined aquifer (Qvr?) that is referred to as the Casavent Aquifer (Robinson & Noble, 1998). A transmissivity value of approximately 600,000 gallons/day/foot and a storage coefficient of 0.15 were reported for the Casavent Aquifer.

- Robinson & Noble (2000) indicate that groundwater in the Casavent Aquifer is at approximate Elevation 300 to 310 feet in the immediate vicinity of the wells and likely flows to the north and/or northwest, toward the Nisqually River.

- Groundwater flow in both the Qva and Qc aquifers is generally toward marine bodies and major streams.

- Groundwater elevations in the Qva and Qc aquifers range from over 600 feet above mean sea level in the eastern portion of the Muck/Murray subbasin to generally less than 75 feet above mean sea level near Puget Sound.

- The Graham Hill Mutual Water Company operates three production wells near the eastern boundary of the Muck/Murray subbasin. All three wells are completed at depths ranging between approximately 330 and 400 feet (Sergerson, 1998). It is likely that these wells are completed within the Qc or TQu aquifers. The static water Elevations in the Graham Hill wells range from approximately 625 to 640 feet above mean sea level (Bell, 2001).

- Static groundwater levels in the Graham Hill area (Muck/Murray subbasin) indicate that a generally southwest-northeast trending groundwater divide is located on Graham Hill (Robinson & Noble, 1996). Groundwater located north of the divide likely flows into the Muck/Murray Creek drainage and potentially into the Clover Creek drainage. Some of the groundwater flowing north of the divide likely discharges via Patterson Springs (T18N R4E, Section 21), which are a headwater of Muck/Murray Creek. Groundwater flow south of the divide is into the South Creek drainage which is a tributary to Muck/Murray Creek.

- Groundwater in the Qva aquifer located beneath the LRI Landfill in the Muck/Murray subbasin (T17N, R4E, Section 10) is at approximate Elevation 600 to 700 feet and flows to the northwest (Kleinfelder, 2001). The groundwater beneath the site likely

provides some recharge to Muck/Murray Creek at some distance northwest of the landfill site (Lakely, 2001).

- Groundwater flow in the Qva and Qc aquifers appears to converge toward McAllister/Abbott Springs and McAllister Creek in the northern portion of the McAllister subbasin (Figure 5.2-5).

- It is likely that the Qvr, Qva and Qc aquifers are in direct hydraulic continuity with each other in portions of the McAllister subbasin, particularly near McAllister and Abbot Springs (Drost and others, 1999; AGI, 1999).

- Groundwater in the Qva and Qc aquifers likely flow toward and provide recharge to the Nisqually River downstream of McKenna (Drost and others, 1999).

- The McKenna Water District operates two production wells (Wells 3 and 4) near the community of McKenna in the Muck/Murray subbasin. The wells are completed at depths of 115 and 212 feet, respectively. Well 3 is reported to be capable of 130 gpm and Well 4 is capable of 270 gpm (Cosmopolitan, 1999). It is likely that these wells are completed within the Qva and/or Qc aquifers.

- The Town of Eatonville operates two production wells located at the water treatment plant adjacent to the Mashel River, in the Mashel subbasin. The wells tap a relatively shallow unconfined aquifer that underlies the Town (Gray & Osborne, 1996). The elevation of the groundwater in the shallow aquifer is approximately 760 feet in the immediate vicinity of the Town.
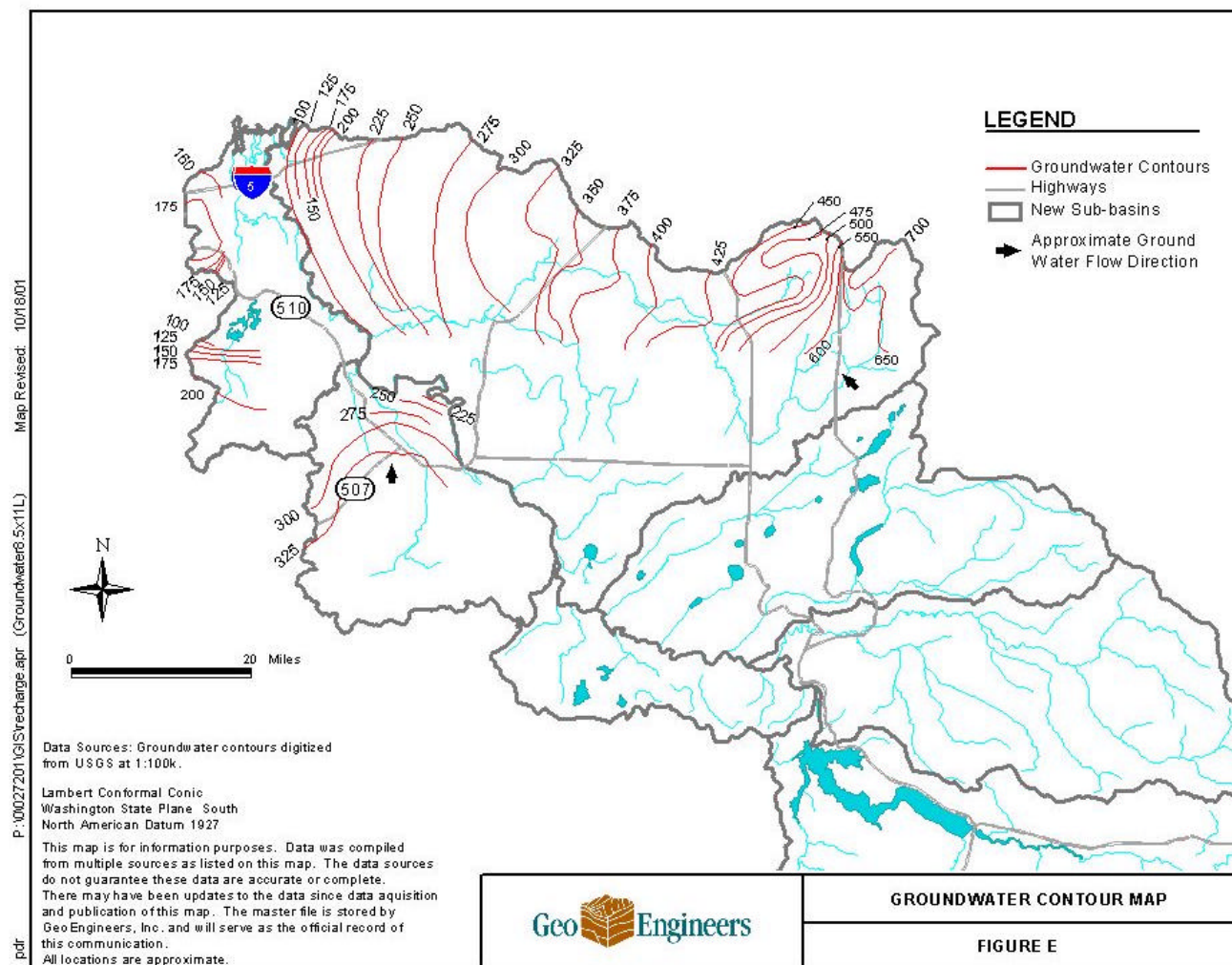
Groundwater contours obtained from Drost and Others (1999) and Griffin and Others (1962). Groundwater flow direction information was obtained from Robinson and Noble (1998, 2001), Bell (2001), and Klienfelden (2001).

Figure 5.2-5. Groundwater contour map.

HYDRAULIC CONTINUITY

GENERAL

Hydraulic continuity refers to the hydraulic interaction between surface and groundwater within the watershed (Ecology, 1998). A surface water body that loses water and recharges groundwater is referred to as "losing" and surface waters that receive flow from groundwater are referred to as "gaining" (Fetter, 1994). Depending on watershed-specific factors, the hydraulic connection between groundwater and surface water may be significant or negligible. These factors are, in part, described by Bredehoeft et al. (1982) and Theis (1940) and include:

- The hydraulic parameters of the aquifer (hydraulic conductivity, storage).

- The vertical and horizontal position of the aquifer in relation to the surface water body.

- The presence (or absence) of confining units or low-permeability zones between the aquifer and stream or lake bed.

- The hydraulic head differential between surface and groundwater.

- The amount of surface or groundwater withdrawal from the regional flow system and the location and timing of withdrawal.

- The hydraulic conductivity and thickness of the bottom sediments of surface water bodies.

- Other physical factors, i.e. water temperature, density, salinity, etc.

Aquifer/Stream Flow Relationship

In almost all watersheds, surface water and groundwater flow systems are hydraulically connected to some degree (Winter et al., 1998). Creeks and rivers may be fed by groundwater driven springs in some areas of the watershed, and water may flow out of a stream and recharge aquifers in other areas. The flow in a stream or river that

originates from groundwater is referred to as "baseflow", and the remaining stream flow is referred to as "runoff" (Fetter, 1994).

For watersheds where the hydraulic connection between surface and groundwater is minimal, groundwater and surface water flow systems may have very little interaction. However, for watersheds where the hydraulic connection between surface and groundwater is significant, groundwater and surface water flows may be inter-dependent. For those types of watersheds, losing streams may lose so much of the stream flow as recharge to aquifers that the stream ceases to flow, and the flow of gaining streams may originate entirely from groundwater, particularly during dry periods when runoff from precipitation is negligible.

Toth (1963) showed that aquifers can be characterized as regional or local flow systems. The deep aquifers of a watershed are likely to comprise regional aquifer systems which receive recharge over a large area and discharge at locations many miles from the primary recharge source. Most watersheds also have many smaller flow systems at the local scale that are composed of shorter recharge and discharge systems. Local flow systems may be further divided into sub-local systems because an individual creek or stream may have many gaining and losing reaches along specific stream reaches (Woessner, 2000).

Groundwater Pumping and Stream Flow

Pumping of groundwater creates a capture-zone, or an area where the equipotential surface is depressed and groundwater flow is directed towards the location of pumping (Fetter, 1994). Previous research has shown that capture zone areas can affect stream flow through both local and regional flow systems over time (Morgan and Jones, 1999). The use of groundwater by pumping can increase recharge to the aquifer from surface water and has the potential to decrease the flow in creeks and rivers through two mechanisms: 1) by decreasing the amount of baseflow provided from groundwater to gaining streams and, 2) by increasing the amount of water seeping from a losing stream as aquifer recharge. The extent and amount of stream flow depletion is dependent upon the watershed-specific factors previously listed.

The rate of natural aquifer recharge from precipitation is frequently misunderstood as a measurement of the "safe yield" at which an aquifer may be pumped without affecting groundwater levels or surface water bodies (Sophocleous, 1997). This concept of safe yield incorrectly assumes that the amount of recharge provided to an aquifer can be

withdrawn without affecting the groundwater flow system or stream flow/aquifer hydrodynamics (similar to a bathtub being filled and drained at the same rate without affecting the water level). However, previous researchers have shown that the influence of groundwater pumping on stream flow is dependent on the dynamic equilibrium established between pumping and the capture of natural groundwater discharge, and is not solely based on the rate of natural recharge available to the aquifer (Ecology, 1998; Torak and others, 1996; Miles and Chambet, 1995; Bredehoeft et al., 1982).

The potential influence on stream flows from the use of surface water is relatively straightforward, because each cubic foot per second (cfs) of surface water removed from the stream is a direct and equal reduction in stream flow. However, the influence of groundwater use on stream flow is more complicated, due to both spatial and temporal factors related to recharge. The recharge area for a specific groundwater point-of-diversion may be spread out over a very large area. Alternatively, the aquifer recharge source(s) may be preferentially connected to an aquifer in specific (often unknown) areas due to the spatial relationship between the aquifer and surface water bodies, aquifer heterogeneity, the presence or absence of confining units or other watershed-specific factors. Also, the timing of groundwater use is critical in evaluating the potential influence of groundwater pumpage on stream flow, especially during the dry summer period when stream flow is lowest (Ecology, 1998). Because of the potential to decrease stream flow, groundwater pumping may indirectly decrease water quality or conflict with the flow requirements for fisheries habitat.

A surface water withdrawal has a direct and instantaneous impact on flow in the stream. However, the impact of groundwater withdrawals on surface water from wells complete in hydraulically connected shallow aquifers is generally equal to the long-term average use (pumping rate) of the well. Therefore, the impact of a groundwater withdrawal on surface water flow in a nearby stream would be closer to the long-term average pumping rate of the well. Furthermore, the effect of the groundwater use would be attenuated out over a significant reach of the stream. For example, if a current surface water use was 1,000 gpm for 12 hours a day, continuously. The effect would be a near instantaneous loss of 1,000 gpm from stream flow in the stream when the pump was operating. However, pumping groundwater at 1,000 gpm for 12 hours a day, continuously, from a well located several hundred feet from the stream would result in an average maximum impact of approximately 500 gpm on the nearby stream, approximately one half of the impact of the surface water withdrawal.

Subbasin Ranking Criteria

Hydraulic continuity is an increasingly important consideration in Washington State. West of the Cascade Divide, many of the aquifers used for water supply are relatively shallow and most creeks and streams receive recharge from groundwater in at least the upper and middle portions of the watersheds. Although it is difficult to generalize the hydrogeologic setting of any area, the groundwater flow systems in the region tend to be complicated. Groundwater recharge and discharge patterns are often unknown, and the effects of groundwater pumping on stream flow can extend over a large area depending on the presence of confining units, aquifer heterogeneity and discharge/recharge zones, many of which are poorly defined or unknown (Morgan and Jones, 1999).

Water resource policy in Washington State is mainly under the regulatory purview of the Washington State Department of Ecology. Ecology generally evaluates the effect of groundwater pumping on stream flow when considering new water rights applications. Although subject to case-by-case considerations, Ecology generally does not allocate new water rights that would cause a decrease of surface water flow in streams that are closed to further appropriation or where the flow is insufficient for habitat requirements. As part of the water rights application process, Ecology has required studies on the potential influence of groundwater pumping on stream flow.

Because evaluating the influence of groundwater use on stream flow is complicated and subject to professional interpretation, Ecology developed a draft guidance manual, "The Report on the Technical Advisory Committee on the Capture of Surface Water by Wells" dated 1998. The guidance manual presents recommended methods for evaluating the influence of groundwater pumping on stream flow. The manual describes three types of watersheds (Level I, II, III) depending on watershed-specific factors including the hydrogeologic setting, water rights priorities, available stream flow, extent of groundwater use, and population density. A recommended level-of-effort for evaluating aquifer/stream flow relationships is presented for each of the three watershed categories, depending on the complexity of the watershed hydrology and the potential for impact from each of the watershed-specific factors, as summarized below and shown on Table 5.2-4.

Table 5.2-4. Summary of generic watershed classification for hydraulic continuity[1].

	Watershed Type		
	Level I	Level II	Level III
Watershed Classification			
Surface Water Rights	Available	Near Closure or Closed to Further Appropriation	Closed to Further Appropriation or Senior Rights Impaired
Regulatory Constraints on Surface Water Flows	None	Potential to Not Meet Instream Flow or Habitat Requirements	Instream Flows or Habitat Requirements Not Met
Existing Ground Water Use	Low	Low to Moderate	Moderate to High
Population	Low	Low to Moderate	Moderate to High
Hydrogeologic Complexity	Low	Low to Moderate	Moderate to High
Recommended Data and Analysis			
Hydrologic Data Required	Simple	Moderate	Complex
Spatial Effects	No	Yes	Yes
Temporal Effects	No	Yes or No (Depends on Watershed-Specific Factors)	Yes
Type of Analysis	Water Balance	Simple Model	Three-dimensional Transient Model

Notes
[1] Based on ranking factors presented in Washington State Department of Ecology 1998 publication, "Draft Report on the Technical Advisory Committee on Capture of Surface Water by Wells."

Level I. These watersheds have a low potential for stream flow to be affected from groundwater use because water-use demand and population density are low. These watersheds may be adequately characterized by fairly simple water balance accounting methods.

Level II. Level II watersheds have a moderate potential for stream flow to be affected by groundwater use, a moderate water-use demand and population density, and an increasingly complex watershed hydrogeology. These watersheds require an increased level of analysis (typically simple numerical modeling) to characterize potential impacts on stream flow from groundwater use.

Level III. These watersheds have a high potential for stream flow to be affected by groundwater use. Water-use demand and population density are high and forecast to increase. The hydrogeology of the watershed is complex, and the effects of groundwater pumping are difficult to quantify and dependent upon temporal factors. These types of watersheds generally require transient, three-dimensional numerical modeling to characterize the potential impacts on stream flow from groundwater use.

HYDRAULIC CONTINUITY ANALYSIS

General

Hydraulic continuity between groundwater and surface water (i.e. steam flow) in the subbasins was evaluated based on:

- The potential for a specific aquifer to be significantly hydraulically connected with surface water.

- The potential for the estimated groundwater use in the subbasins to have an impact on stream flow.

It should be noted that a specific groundwater use might have an insignificant effect on surface water flow in a nearby stream even though the aquifer has some degree of hydraulic continuity with surface water.

Aquifer/Surface Water Continuity

The potential for a specific aquifer to be significantly hydraulically connected with surface water was qualitatively evaluated based on generally known information regard-

ing the aquifer (regional extent, depth, elevation, and whether the aquifer is generally confined or unconfined in nature), as described in previous sections of this report.

For example, the Qvr aquifer is regionally extensive, shallow, located at an elevation above sea level, and unconfined in nature in all of the subbasins. Therefore, the Qvr aquifer has a high potential to be in direct hydraulic continuity with surface water. However, bedrock aquifer (Tb) is generally local, deep, situated significantly below sea level and confined in the McAllister subbasin but it is relatively shallow, above sea level and unconfined to confined in the Mashel subbasin. This indicates that the Tb aquifer has a low potential for hydraulic continuity in the McAllister subbasin and a high potential in the Mashel subbasin. A summary of the hydraulic continuity potential for each primary aquifer in each subbasin is shown on Table 5.2-5.

Table 5.2-5. Aquifer Hydraulic Continuity Potential.

Aquifer	Subbasin					
	McAllister	Muck/Murray	Yelm	Toboton/ Powell/ Lackamas	Tanwax/ Kreger/ Ohop	Mashel
Qvr	High	High	High	High	High	High
Qva	Moderate	Moderate	Moderate	High	High	High
Qc	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Tqu	Low	Low	Low	Low	Low	Low
Tb	Low	Low	Low	Moderate	Moderate	High

Groundwater Use Impact on Stream Flow

Data were compiled on the factors affecting the influence of groundwater use on stream flow for each of the subbasins from the previous evaluations conducted for this project. These subbasin-specific factors included:

- Water use (groundwater and surface water use)
- Population (current and projected)
- Hydrogeologic complexity of watershed
- Water rights status
- Fish habitat flow requirements

These categories of data were ranked according to the criteria recommended by Ecology for evaluating aquifer/stream flow relationships (Ecology, 1998). The subbasin-specific rankings are summarized in Table 5.2-6.

The purpose of developing this ranking system was to determine the appropriate subbasin classification and recommended level-of-effort (i.e. water balance, spatial modeling, etc.) for evaluating aquifer/stream flow relationships in each subbasin. The subbasin classifications were compared to the available data to determine if sufficient information was available to assess the potential influence of groundwater use on stream flow based on the subbasin complexity. If insufficient data or analyses were available to make conclusions regarding the potential impacts from groundwater on stream flow, recommendations were provided for further assessment. The hydraulic continuity evaluation for each subbasin is presented below.

McAllister

Using the ranking criteria recommended by Ecology and the available data, McAllister subbasin would be classified as a Level III watershed for the following reasons:

- The large use of groundwater from a multiple aquifer/confining unit system.

- The large use of surface water from McAllister springs, which is almost totally supplied by groundwater.

- High current and future population density.

- The lack of available surface water rights.

- The high current and projected population and water-use demand.

- The flow restrictions placed on Eaton Creek.

Table 5.2-6. Hydraulic Continuity Ranking for Specific Subbasins

	Subbasins					
	McAllister	Muck/Murray	Yelm	Toboton/ Powell/ Lackamas	Tanwax/ Kreger/ Ohop	Mashel
Surface Water Rights[1]	Closed	Murray Has Seasonal Restrictions/Muck is Closed	Closed	Seasonal Closure	Seasonal Closure Ohop Closed	Seasonal Closure
Regulatory Constraints on Surface Water Flows[1]	Flow restrictions on Eaton Creek	Flow restrictions on Muck Creek	Flow restriction on Yelm Creek		Flow restrictions on Ohop Creek	Does not meet minimum instream flows
Water Use Demand	High	Moderate	Moderate	Low	Low	Low
Population Density	High	Moderate	Moderate	Low	Low	Low
Hydrogeologic Complexity	High	High	High	Moderate	Moderate	Low
Watershed Classification[2]	Level III	Level II	Level II	Level I	Level II	Level II

Notes
  [1] See Chapter 5.3 of report for details on stream closure and instream flow restrictions.
  [2] Subbasin classification based on ranking factors presented in Washington State Department of Ecology 1998 publication, "Draft Report on the Technical Advisory Committee on the Capture of Surface Water by Wells."

Sufficient data are available for a preliminary evaluation of hydraulic continuity in the subbasin. Based on our understanding of the subbasin hydrology, the available information and the subbasin factors presented above, a water balance assessment will likely be of limited usefulness in evaluating the potential impact of subbasin wide groundwater use on streamflow. More detailed quantitative spatial analysis is required in this subbasin to evaluate the effects of expanded and/or site specific groundwater use on stream flow.

Groundwater use in McAllister subbasin is from deep and shallow aquifer systems. A comprehensive data set is available to evaluate the potential influence of widespread pumping on stream flow within the subbasin. We understand that AGI/CDM is currently in the process of developing a detailed groundwater flow model of the McAllister Spring area based partly on previous models and partly on new information. We also understand that this model is schedule for completion sometime in the springof 2002. It is anticipated that this new model will help better defined groundwater flow and potential impacts to surface water from groundwater use in the McAllister subbasin.

Muck/Murray

We have classified the Muck/Murray subbasin as a Level II watershed for the following reasons:

- The moderate use of groundwater from a multiple aquifer/confining unit system.

- Moderate current and future population density.

- The lack of available surface water rights on Muck/Murray Creek and seasonal closure restrictions on Murray Creek.

- The moderate and current projected population and water-use demand.

- Areas of concentrated groundwater use (McKenna, Roy, Graham Hill).

Sufficient data are available for a preliminary evaluation of hydraulic continuity in the subbasin. Based on our understanding of the subbasin hydrology, available information and the subbasin factors presented above, a water balance assessment will likely be an adequate methodology to evaluate, in a general qualitative manner, the potential impact of subbasin wide groundwater use on streamflow. Therefore, a water

balance evaluation of the subbasin is warranted and useful. However, more detailed quantitative spatial analysis is required to evaluate the effects of expanded and/or site specific groundwater use on stream flow, particularly in areas of concentrated groundwater use such as the Towns of McKenna and Roy, and the Graham Hill area.

Yelm

We have classified the Yelm subbasin as a Level II watershed for the following reasons:

- The moderate use of groundwater from a multiple aquifer/confining unit system.

- Moderate current and future population density.

- The lack of available surface water rights on Yelm Creek.

- The moderate and current projected population and water-use demand.

- Areas of concentrated groundwater use (City of Yelm).

Sufficient data are available for a preliminary evaluation of hydraulic continuity in the subbasin. Based on our understanding of the subbasin hydrology, available information and the subbasin factors presented above, a water balance assessment will likely be an adequate methodology to evaluate, in a general qualitative manner, the potential impact of subbasin wide groundwater use on streamflow. Therefore, a water balance evaluation of the subbasin is warranted and useful. However, more detailed quantitative spatial analysis is required to evaluate the effects of expanded and/or current site specific groundwater use on streamflow, particularly in areas of concentrated groundwater use such as the City of Yelm or in areas that are near closed or flow restricted streams.

Toboton/Powell/Lackamas

We have classified the Toboton/Powell/Lackamas subbasin as a Level I watershed for the following reasons:

- The low use of groundwater from a moderately complex aquifer system.

- The low current and projected population and water-use demand.

- Lack of areas of concentrated high yield groundwater use.

Sufficient data are available for a preliminary evaluation of hydraulic continuity in the subbasin. Based on our understanding of the subbasin hydrology, available information and the subbasin factors presented above, a water balance assessment will likely be an adequate methodology to evaluate, in a general qualitative manner, the potential impact of subbasin wide groundwater use on streamflow. Therefore, a water balance evaluation of the subbasin is warranted and useful. However, more detailed quantitative spatial analysis is required to evaluate the effects of expanded, proposed and/or current site specific groundwater use on streamflow, particularly in areas of the subbasin with current or proposed concentrated groundwater use or areas that are within one mile of streams that are either closed to further withdrawals or have instream flow restrictions.

Tanwax/Kreger/Ohop

We have classified the Tanwax/Kreger/Ohop subbasin as a Level II watershed for the following reasons:

- The low use of groundwater from a moderately complex aquifer system.

- The lack of available surface water rights on Ohop Creek.

- Seasonal closure of surface water rights on Tanwax/Kreger/Ohop Creek and tributaries (Chapter 5.3).

- The low current and projected population and water-use demand.

Sufficient data are available for a preliminary evaluation of hydraulic continuity in the subbasin. Based on our understanding of the subbasin hydrology, available information and the subbasin factors presented above, a water balance assessment will likely be an adequate methodology to evaluate, in a general qualitative manner, the potential impact of subbasin wide groundwater use on streamflow. Therefore, a water balance evaluation of the subbasin is warranted and useful. However, more detailed quantitative spatial analysis is required to evaluate the effects of expanded and/or current site specific groundwater use on streamflow, particularly in areas of concentrated groundwater use or in areas that are near closed or flow restricted streams.

Mashel

We have classified the Mashel subbasin as a Level II watershed for the following reasons:

- Surface water rights on the Mashel River are subject to seasonal restrictions.

- Areas of concentrated groundwater use (Town of Eatonville).

- The low use of groundwater from a moderately complex aquifer system.

- The low and current and projected population and water-use demand.

- Generally low hydrogeologic complexity.

Sufficient data are available for a preliminary evaluation of hydraulic continuity in the subbasin. Based on our understanding of the subbasin hydrology, available information and the subbasin factors presented above, a water balance assessment will likely be an adequate methodology to evaluate, in a general qualitative manner, the potential impact of subbasin wide groundwater use on streamflow. Therefore, a water balance evaluation of the subbasin is warranted and useful. However, more detailed quantitative spatial analysis is required to evaluate the effects of expanded and/or current site specific groundwater use on streamflow, particularly in areas of concentrated groundwater use like near the Town of Eatonville or in areas that are near closed or flow restricted streams.

WATER BALANCE ANALYSIS

GENERAL

Average monthly climatic water balances were evaluated for each of the subbasins. The climatic water balance equation is shown below and is based on Freeze and Cherry (1979).

$$PPT = ET + RCH + SRO \quad (Eq. 1)$$

Where:

PPT = Precipitation

ET = Evapotranspiration

RCH = Groundwater Recharge

SRO = Surface Water Runoff

Water balances are used to evaluate the distribution of the various components of the subbasin hydrology between the overall hydrologic system. The purpose of a water balance is to complete a simple evaluation of the relative influence of an existing or proposed water use on the overall water resources of a subbasin. For this analysis, the water balance was used to compare an approximate estimate of groundwater recharge to an estimate of water rights/use and residential consumptive water use in the subbasins. A detailed description of the methodology used to estimate water rights/use and residential consumptive water use in the subbasins is presented Chapter 5, Section 5.3 of this report. For this Level I Technical Assessment, water balances were used as a general qualitative screening tool to identify subbasins where more detailed analyses may be necessary. It is important to recognize the limitations of water balances in evaluating water resources, as described below.

- Water balances are not adequate to evaluate the potential influence of an increase in groundwater use for subbasins with complex hydrology or large groundwater use. This is because groundwater use is dependent upon aquifer hydraulics, spatial and temporal characteristics and the capture of natural discharge and water balances can not be used to accurately evaluate any of these factors (Bredehoeft 1997, Sophocleous, 1997; Bredehoeft et al., 1982).

- Hydrologic components are presented as total monthly averages from 1961 to 1990 based on the available data. Climatic and streamflow data are not available for some subbasins within this time period and were estimated.

- Steady-state (static) conditions are assumed to be an accurate representation of the hydrologic system within each subbasin. In reality, the subbasins are actually transient systems that are dynamically balanced between water inputs and output. Subbasins with significant consumptive use and complex watershed hydrology should be evaluated as transient systems.

- The subbasin boundaries were assumed identical for the surface water and groundwater hydrologic systems. In reality, the groundwater flow system boundary conditions are complex, and the groundwater boundaries are likely not identical to the surface water boundaries for many of the subbasins.

- The water balance assessment does not incorporate inter-watershed water transfer. It is possible that groundwater is transferred between subbasins during periods of extended groundwater pumping.

- Both surface and groundwater use were assumed to originate from stream baseflow (instead of stream runoff) due to the limited information available to differentiate between surface water and groundwater use. This is likely to be a valid assumption for surface water use for most of the subbasins. However, the relationship between groundwater use and stream flow has not been established for many of the subbasins. It is likely that a significant component of groundwater use is derived from aquifer throughflow or storage, and only a portion of groundwater use is derived from baseflow.

- Water balances are only valid to describe existing conditions where sufficient empirical data is available. Water balances are widely recognized as inappropriate for predictive analysis due to the simplifying assumptions and the inability of the method to predict changes in hydrologic systems (Bredehoeft et al., 1982; Sokolov and Chapman, 1974).

WATER BALANCE COMPONENTS

The methods used to evaluate each of the water balance components are presented below.

Precipitation

The water balance assessment was conducted using monthly averages of precipitation obtained from the data set described in Chapter 2.0. Annual and monthly precipitation rates for each of the subbasins were calculated from the isohyetal precipitation distribution map of the WRIA as discussed previously in this report.

Evapotranspiration

Potential evapotranspiration for each subbasin was calculated using the Thornthwaite method (Dunne and Leopold, 1978). The Thornthwaite method is an empirical equation that incorporates average monthly air temperatures to calculate potential evapotranspiration. The average monthly air temperatures within each subbasin were generally calculated from the nearest recording station(s) with data from 1961 to 1990 (Chapter 2.0). Air temperature data was not available for all of the subbasins during the

period from 1961 through 1990. If air temperature data was unavailable for the entire period of record from 1961 through 1990, the monthly average air temperature was normalized to the data from the closest recording station with complete data. If air temperature records were unavailable, the monthly average air temperature was estimated from the closest recording station.

The actual evapotranspiration was estimated to equal potential evapotranspiration from late-fall (October or November) through early spring (March or April), when evapotranspiration approaches total evapotranspiration (Dunne and Leopold, 1978). During the remainder of the year, evapotranspiration was calculated as the difference of groundwater recharge and surface water runoff from precipitation.

Surface Water Runoff

Surface water flow in streams in the study area is generally comprised of surface water runoff and groundwater flow into the stream (baseflow). The 50 percent and 90 percent exceedance flows for the subbasin streams are summarized in Tables 5.1-4, 5.1-5, and 5.1-6. Ecology completed a baseflow/surface water runoff analyses for numerous Washington rivers and streams using the USGS flow gaging data (Sinclair and Pitz, 1999). Estimates of surface water runoff and baseflow were reported for the several streams located in the Mashel, Tanwax/Kreger/Ohop and Muck/Murray subbasin. Streamflow/baseflow estimates were generally lacking for the remaining subbasins. For these subbasins, streamflow percentage was assumed relatively consistent with percentages estimate for a nearby subbasin based on the topography, geology and size of the subbasin drainage area. Therefore, we assumed that the percentage of surface water runoff in the Yelm and Toboton/Powell/Lackamas subbasins was similar to the values reported for the Muck/Murray and Tanwax/Kreger/Ohop subbasins, respectively, for the purposes of this water balance analysis (Sinclair and Pitz, 1999). We also assumed negligible surface water runoff in the McAllister subbasin.

The surface water runoff estimates were calculated by Sinclair and Pitz (1999) using the hydrograph separation program HYSEP (Sloto and Crouse, 1996) which is based on the methods of Pettyjohn and Henning (1979). Hydrograph separation methods are intended to evaluate natural flows in watersheds. Hydrograph separation assumes minimal changes in watershed runoff from snowpack, urbanization, retention/detention facilities, reservoirs, or any other factor that violates the simple conceptual watershed model assumed by the method (Linsley et al., 1983). The advantage of hydrograph separation is that it provides a relatively simple method for estimating the surface water

runoff contribution to stream flow, but the disadvantage is that it can lead to erroneous runoff/baseflow estimates if the gage records do not reflect natural flows or include significant flow from snowpack melt (Mau and Winter, 1997). The runoff calculations by Sinclair and Pitz (1999) can be considered rough estimates for subbasins that do not violate the assumptions of the hydrograph separation method and may be accurate during periods when runoff from snowpack melt is minimal and for watersheds where the gage records still reflect natural flows.

Groundwater Recharge

Monthly and annual groundwater recharge rates for each subbasin were estimated by subtracting the estimated losses of evapotranspiration and surface water runoff from the precipitation totals as shown on Table 5.2-7. Data Reliability

Quantitative information on precipitation, evapotranspiration, and surface water runoff are needed to construct the simplistic water balances for each subbasin. Unfortunately, accurate, independent measurements for some of these parameters are not available for all areas of WRIA 11, and many of the values have to be determined using empirical estimates that can be subject to large errors. Therefore, a detailed statistical evaluation of the overall reliability of the water balance calculations is impossible. It should be noted that the water balance evaluation of recharge in the subbasins was intended to be used as a qualitative screening tool to identify subbasins that may be experiencing or may have the potential to experience water supply/stream flow problems.

Table 5.2-7. Summary of Climatic Water Balance.

Subbasin	Component	Month												
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
McAllister	Precipitation	3.8	6.7	7.0	6.6	4.9	4.4	3.0	2.2	1.8	0.8	1.3	2.3	44.8
	Evapotranspiration	1.8	0.9	0.5	0.4	0.7	1.2	1.8	2.2	1.8	0.8	1.3	2.3	15.6
	Surface Water Runoff	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Recharge	2.1	5.9	6.5	6.2	4.2	3.3	1.2	0.0	0.0	0.0	0.0	0.0	29.3
Muck/Murray	Precipitation	3.5	5.9	6.2	5.9	4.4	4.2	3.1	2.2	2	0.9	1.4	2.3	42.0
	Evapotranspiration	1.8	0.9	0.5	0.4	0.7	1.1	1.8	2.1	2.0	0.9	1.4	2.3	16.0
	Surface Water Runoff	0.0	0.2	0.4	0.7	0.5	0.3	0.2	0.1	0.0	0.0	0.0	0.0	2.3
	Recharge	1.7	4.8	5.3	4.8	3.2	2.8	1.1	0.0	0.0	0.0	0.0	0.0	23.7
Yelm	Precipitation	3.7	6.1	6.5	6.1	4.6	4.2	3.2	2.2	1.8	0.8	1.3	2.3	42.8
	Evapotranspiration	1.8	0.9	0.5	0.4	0.7	1.1	1.8	2.1	1.8	0.8	1.3	2.3	15.6
	Surface Water Runoff	0.0	0.2	0.4	0.7	0.5	0.3	0.2	0.1	0.0	0.0	0.0	0.0	2.3
	Recharge	1.9	5.1	5.6	5.0	3.4	2.8	1.2	0.0	0.0	0.0	0.0	0.0	24.9
Toboton/ Powell/ Lackamas	Precipitation	3.2	5.0	5.7	5.1	3.8	3.9	2.9	2.3	1.9	0.8	1.4	2.5	38.5
	Evapotranspiration	1.9	0.9	0.6	0.5	0.8	1.1	1.8	1.9	1.5	0.7	1.3	2.4	15.1
	Surface Water Runoff	0.4	0.9	1.1	1.1	1.0	0.7	0.6	0.4	0.4	0.1	0.1	0.1	7.0
	Recharge	0.9	3.2	4.0	3.5	2.0	2.1	0.5	0.0	0.0	0.0	0.0	0.0	16.4
Tanwax/ Kreger/ Ohop	Precipitation	4.0	6.1	6.7	6.4	4.7	4.5	3.5	2.7	2.4	1.0	1.7	2.5	46.2
	Evapotranspiration	1.8	0.8	0.5	0.3	0.7	1.0	1.7	2.3	2.0	0.9	1.6	2.4	15.9
	Surface Water Runoff	0.4	0.9	1.1	1.1	1.0	0.7	0.6	0.4	0.4	0.1	0.1	0.1	7.0
	Recharge	1.9	4.4	5.1	5.0	3.0	2.8	1.2	0.0	0.0	0.0	0.0	0.0	23.3
Mashel	Precipitation	6.3	9.5	10.9	10.8	7.7	6.8	5.0	3.7	3.2	1.3	2.1	3.4	70.7
	Evapotranspiration	1.8	0.8	0.5	0.3	0.7	1.0	1.7	2.9	2.4	1.1	2.0	2.9	18.0
	Surface Water Runoff	0.8	2.2	3.1	2.3	2.6	1.7	1.1	0.8	0.8	0.2	0.1	0.2	15.8
	Recharge	3.7	6.5	7.4	8.2	4.5	4.1	2.2	0.0	0.0	0.0	0.0	0.3	36.9

WATER BALANCE DATA ANALYSIS

GENERAL

The groundwater recharge values estimated using the climatic water balance methodology compared well to, if not slightly greater than, the recharge values estimated by the USGS methodology in four of the six subbasins (Table 5.2-3). However, the water balance estimated recharge values for the Tanwax/Kreger/Ohop and Mashel subbasins are significantly greater than the values estimated using the USGS method. It is our opinion that the water balance methodology may significantly over estimate groundwater recharge in the Tanwax/Kreger/Ohop and Mashel subbasins due to limitations with determining the percentage of surface water runoff from the stream flow records (Sinclair and Pitz, 1999). Both the Tanwax/Kreger/Ohop and Mashel subbasins have significant areas of steep bedrock topography where it is reasonable to assume that the percentage of precipitation that becomes surface water runoff is significantly greater than 50 percent. However, the percentage of surface water runoff estimated by Sinclair and Pitz (1999) in these basins is significantly less than 50 percent resulting in a much higher groundwater recharge value.

To allow a conservative comparison of estimated groundwater recharge and water use in the subbasins, water use was compared to both the USGS and water balance annual recharge values. Again it should be noted that groundwater use in the subbasins is derived from groundwater recharge as well as aquifer throughflow and/or storage. It is likely that in many of the subbasins a significant volume of groundwater use is derived from aquifer throughflow and/or storage. The annual groundwater recharge values from Table 5.2-3 are compared to allocated water rights and the net residential water use values for each subbasin in Table 5.2-8. It should be noted that "allocated water rights" are paper water rights. These allocated water rights are assumed to be fully utilized for the purposes of this Level I assessment. Net residential water use includes an estimate of the net water use by domestic exempt wells in each subbasin. A detailed discussion of how the allocated water rights were estimated is presented in Chapter 5.4 of this report. Values of Allocated Water Rights and Net Depletion/Residential use were obtained from Table 5.4-21 in Chapter 5.4. The values in Table 5.4-21 were converted from cubic feet per second (cfs) to inches per month by multiplying the cfs by the number of seconds in each month and dividing by the subbasin area. The monthly totals were then summed to equal the yearly totals in inches, as shown in Table 5.2-8. The results of the water balance assessment are described below for each subbasin.

Table 5.2-8. Comparison of Groundwater Recharge to Water Use.

	Groundwater	Allocated Water	Net Depletion/Residential	
Subbasin	Recharge	Rights	2000	2020
McAllister	29.3/26.6	24.1 (82.2-90.6)	0.44 (1.5 - 1.7)	0.66 (2.3 - 2.5)
Muck/Murray	23.7/21.5	1.91 (8.1 – 8.9)	0.15 (0.6 - 0.7)	0.20 (0.8 – 0.9)
Yelm	24.9/22.3	1.14 (4.6 – 5.1)	0.21 (0.8 – 0.9)	0.32 (1.3 – 1.4)
Toboton/Powell/ Lackamas	16.4/15.2	0.23 (1.4 – 1.5)	0.06 (0.3 – 0.4)	0.09 (0.5 – 0.6)
Tanwax/Kreger/Ohop	23.3/16.6	0.14 (0.6 – 0.8)	0.05 (0.2 – 0.3)	0.07 (0.3 – 0.4)
Mashel	36.9/22.5	0.10 (0.3 – 0.4)	0.02 (0.05 – 0.09)	0.03 (0.08 – 0.1)
Notes All values are in inches. Numbers in parenthesis are percent of groundwater recharge. Climatic water balance value/USGS precipitation-recharge method value				

McAllister

When the water balance methodology described above is applied to the McAllister subbasin, it yields results showing the subbasin receives approximately 45 inches of precipitation annually with roughly 59 to 65% ending up as groundwater recharge (Table 5.2-8). Estimates of allocated water in the subbasin due to water rights have been estimated at approximately 24 inches/year, or roughly 82 to 91 percent of groundwater recharge (Table 5.2-8). Approximately 23 inches/year is due to surface water rights and roughly 1 inch/year is due to groundwater rights. The 1.0 inch reduction due to groundwater use is approximately 3 to 4 percent of the estimated groundwater recharge in the basin.

The net depletion of surface water resources in the McAllister subbasin due to residential use was estimated at 0.44 inches for the year 2000 and 0.66 for the year 2020 (Table 5.2-8). Therefore, the net depletion due to residential water use is currently slightly less than 2 percent of groundwater recharge and likely could increase to 2.5 percent by the 2020.

Conclusions

The water balance and water use analysis completed for this Level I assessment indicate that the net depletion to water resources in the subbasin due to the currently

allocated water rights may comprise up to roughly 80 to 90 percent of the estimated groundwater recharge in the basin, with less than 2 percent the result of residential water use. Based on this analysis it would appear that the potential influence of water use on streamflow is high at the watershed scale in the McAllister subbasin. However, it is likely that a significant volume of the water derived from the subbasin originates as groundwater throughflow. Drost et al (1999) estimated total recharge in the area at 310,000 acre-ft, which is many times higher than the recharge estimated here. Therefore, the overall impact of water use on streamflow in the subbasin is likely significantly less than the 80 to 90 percent as indicated by this analysis. Additional analysis of the groundwater flow system, beyond the scope of this Level I Assessment, would be necessary to quantify the impact of groundwater throughflow on streamflow and water use in the McAllister subbasin. The AGI/CDM model currently under development may provide better information for evaluating overall water budget in the subbasin.

Muck/Murray

The Muck/Murray subbasin receives approximately 42 inches of precipitation annually with roughly 51 to 56% ending up as groundwater recharge (Table5.2-8). Estimates of allocated water rights in the subbasin have been estimated at approximately 2 inches per year (Table 5.2-8). Therefore, current allocated surface/groundwater rights could comprise approximately 8 to 9 percent of the estimated groundwater recharge in the Muck/Murray subbasin.

The net depletion of surface water resources in the Muck/Murray subbasin due to residential use was estimated at 0.15 inches for the year 2000 and 0.20 for the year 2020 (Table 5.2-8). This indicates that the net depletion due to residential water use is currently approximately 0.7 percent of groundwater recharge and likely could increase to approximately 1 percent by the 2020.

Conclusions

The water balance and water use analysis completed for this Level I assessment indicate that the net depletion to water resources in the Muck/Murray subbasin due to the currently allocated water rights may comprise approximately 8 to 9 percent of the estimated groundwater recharge in the basin. Therefore, the potential influence of water use on recharge and streamflow is moderate at the watershed scale in this subbasin.

Yelm

The Yelm subbasin receives approximately 43 inches of precipitation annually with roughly 52 to 58% ending up as groundwater recharge (Table 5.2-8). Estimates of allocated water rights in the subbasin have been estimated at approximately 1.1 inches per year (Table 5.2-8). Therefore, current allocated surface/groundwater rights could comprise approximately 5 percent of the estimated groundwater recharge in the Yelm subbasin.

The net depletion of surface water resources in the Yelm subbasin due to residential use was estimated at 0.21 inches for the year 2000 and 0.32 for the year 2020 (Table 5.2-8). This indicates that the net depletion due to residential water use is currently approximately 1.0 percent of groundwater recharge and likely could increase to approximately 1.5 percent by the 2020.

Conclusions

The water balance and water use analysis completed for this Level I assessment indicate that the net depletion to water resources in the Yelm subbasin due to the currently allocated water rights may comprise approximately 5 percent of the estimated groundwater recharge in the basin. Therefore, the potential influence of water use on recharge and streamflow is moderate at the watershed scale in this subbasin.

Toboton/Powell/Lacamas

The Toboton/Powell/Lacamas subbasin receives approximately 39 inches of precipitation annually with roughly 39 to 42% ending up as groundwater recharge (Table 5.2-8). Estimates of allocated water rights in the subbasin have been estimated at approximately 0.23 inches per year (Table 5.2-8). Therefore, current allocated surface/groundwater rights could comprise approximately 1.5 percent of the estimated groundwater recharge in this subbasin.

The net depletion of surface water resources in the Toboton/Powell/Lackamas subbasin due to residential use was estimated at 0.06 inches for the year 2000 and 0.09 for the year 2020 (Table 5.2-8). This indicates that the net depletion due to residential water use will likely remain less than one percent of groundwater recharge through 2020.

Conclusions

The water balance and water use analysis completed for this Level I assessment indicate that the net depletion to water resources in the Toboton/Powell/Lackamas subbasin due to the allocated water rights and net residential use is likely less than approximately 2 percent of the estimated groundwater recharge in the basin through 2020. Therefore, the potential influence of water use on recharge and streamflow is low at the watershed scale in this subbasin. Furthermore, the water balance analyses are sufficient to evaluate water resource demands within this subbasin.

Tanwax/Kreger/Ohop

The Tanwax/Kreger/Ohop subbasin receives approximately 46 inches of precipitation annually with roughly 36 to 51% ending up as groundwater recharge (Table 5.2-8). Estimates of allocated water rights in the subbasin have been estimated at approximately 0.14 inches per year (Table 5.2-8). Therefore, current use of allocated surface/groundwater rights could comprise approximately 0.8 percent of the estimated groundwater recharge in this subbasin.

The net depletion of surface water resources in the Tanwax/Kreger/Ohop subbasin due to residential use was estimated at 0.05 inches for the year 2000 and increasing to 0.07 by the year 2020 (Table 5.2-8). This indicates that the net depletion due to residential water use will likely remain less than 1.5 percent of groundwater recharge through the 2020.

Conclusions

The water balance and water use analysis completed for this Level I assessment indicate that the net depletion to water resources in the Tanwax/Kreger/Ohop subbasin due to the allocated water rights and net residential use will be less than approximately 1.5 percent of the estimated groundwater recharge in the basin through 2020. Therefore, the potential influence of water use on recharge and streamflow is low at the watershed scale in this subbasin. Furthermore, the water balance analyses are sufficient to evaluate water resource demands within this subbasin.

Mashel

The Mashel subbasin receives approximately 71 inches of precipitation annually with roughly 32 to 52% ending up as groundwater recharge (Table 5.2-8). Estimates of allocated water rights in the subbasin have been estimated at approximately 0.10 inches per year (Table 5.2-8). Therefore, current allocated surface/groundwater rights could comprise less than 1.0 percent of the estimated groundwater recharge in this subbasin.

The net depletion of surface water resources in the Mashel subbasin due to residential use was estimated at 0.02 inches for the year 2000 and increasing to 0.03 by the year 2020 (Table 5.2-8). This indicates that the net depletion due to residential water use will likely remain significantly less than one percent of groundwater recharge through 2020.

Conclusions

The water balance and water use analysis completed for this Level I assessment indicate that the net depletion to water resources in the Mashel subbasin due to the allocated water rights and net residential use will be less than one percent of the estimated groundwater recharge in the basin through 2020. Therefore, the potential influence of water use on recharge and streamflow is low at the watershed scale in this subbasin. Furthermore, the water balance analyses are sufficient to evaluate water resource demands within this subbasin.

DATA GAPS AND LEVEL II RECOMMENDATIONS

The Level I Assessment indicates that the McAllister subbasin may have potential significant conflicts in water resource demands that require additional evaluation and data collection. We understand that additional data is being developed for the McAllister subbasin from watershed planning/groundwater modeling activities currently being completed by the Cities of Olympia and Lacey. Muck/Murray and the Yelm subbasins also have the potential for significant water resource conflicts; given the anticipated growth, development, increase in water use and potential for water quality degradation that is forecasted for these watersheds. The Toboton/Powell/Lackamas, Tanwax/Kreger/Ohop, and Mashel subbasins all are anticipated to have low potential water resource conflicts based on the current and 20-year projected population growth data.

RECOMMENDATIONS

The following are the recommended steps for resolving critical data gaps. These are also discussed in Chapter 7 of this report.

- Perform a detailed evaluation of the groundwater flow models (USGS/AGI/CDM) developed for the McAllister and portions of the Yelm subbasins. Determine if the model(s) can be used to provide realistic approximations of groundwater/surface water interaction under specific groundwater use scenarios in the subbasins (McAllister/Yelm). This evaluation should be conducted in collaboration with regional purveyors and Ecology.

- Utilize the groundwater flow model(s) to assess potential stream/groundwater interaction for the various aquifers. If possible use the groundwater model(s) as a tool to assist in making regional water resource management decisions.

- Use the groundwater flow model(s) for evaluating potential water resource management options for future groundwater development such as streamflow augmentation, induced recharge, optimization of well placement and seasonal timing of pumping to reduce aquifer drawdown and streamflow depletion in the McAllister and Yelm subbasins.

- Complete a detailed evaluation of groundwater use in the Yelm and Muck/Murray subbasins. One of the goals of this evaluation would be to identify/quantify specific areas of high groundwater use.

- Evaluate the potential effect of these high groundwater use areas on the flow in nearby streams with seasonal flow problems. We anticipate that the groundwater flow model developed by others (USGS/AGI/CDM) can be used to evaluate these specific areas in the Yelm subbasin. The potential impact of other high groundwater use areas located in the Muck/Murray subbasin could be evaluated using site-specific analytical modeling and/or numerical modeling, if necessary.